2002P20398 35

(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 909 403 B1

(12) # EUROPEAN PATENT SPECIFICATION

(45) Date of publication and mention of the grant of the patent: **02.10.2002 Bulletin 2002/40**

(51) Int Cl.7: **G02F 1/313**, G02F 1/01, H04J 14/02

(21) Application number: **97934522.0**

(86) International application number: **PCT/EP97/03972**

(22) Date of filing: **23.07.1997**

(87) International publication number: **WO 98/004954 (05.02.1998 Gazette 1998/05)**

(54) **TUNABLE ADD/DROP OPTICAL DEVICE**

ABSTIMMBARE OPTISCHE EINFÜGE-/AUSBLENDVORRICHTUNG

DISPOSITIF OPTIQUE AJUSTABLE D'INSERTION/EXTRACTION

(84) Designated Contracting States:
CH DE DK GB IT LI

(30) Priority: **26.07.1996 IT MI961591**
03.04.1997 IT MI970772

(43) Date of publication of application:
21.04.1999 Bulletin 1999/16

(73) Proprietor: **STMicroelectronics S.r.l.**
20041 Agrate Brianza (Milano) (IT)

(72) Inventors:
- **FINCATO, Antonio**
  I-28062 Cameri (IT)
- **LENZI, Maurizio**
  I-28100 Novara (IT)
- **DI MOLA, Domenico**
  I-20090 Buccinasco (IT)

(74) Representative: **Ferreccio, Rinaldo**
c/o Botti & Ferrari S.r.l.,
Via Locatelli, 5
20124 Milano (IT)

(56) References cited:
US-A- 5 249 243

- **KYO INOUE ET AL: "TUNABLE GAIN EQUALIZATION USING A MACH-ZEHNDER OPTICAL FILTER IN MULTISTAGE FIBER AMPLIFIERS" IEEE PHOTONICS TECHNOLOGY LETTERS, vol. 3, no. 8, 1 August 1991, pages 718-720, XP000223738**
- **YAFFE H H ET AL: "RESONANT COUPLERS ACTING AS ADD-DROP FILTERS MADE WITH SILICA-ON-SILICON WAVEGUIDE TECHNOLOGY" JOURNAL OF LIGHTWAVE TECHNOLOGY, vol. 12, no. 6, 1 June 1994, pages 1010-1014, XP000484219**
- **KOSTRZEWA C ET AL: "BANDWIDTH OPTIMIZATION OF ADD/DROP FILTER USING A CASCADED COUPLER MACH-ZEHNDER CONFIGUARATION" 1 January 1995, PROCEEDINGS EUROPEAN CONFERENCE ON INTEGRATED OPTICS WITH TECHNICAL EXHIBIT, VOL. 1, PAGE(S) 521 - 524 XP000566151**

EP 0 909 403 B1

[0017] In other words, all the channels that are not the object of the channel drop operation performed by the device, are available on an output gate of the device in a substantially nonattenuated state, while the selected channel is strongly attenuated (bar response characteristics traced with a continuous line). A dual situation occurs on the other output gate (cross response characteristics traced with a dash line) whereas the channel to be extracted is available in a substantially nonattenuated form while all the other (deselected) channels are strongly attenuated.

[0018] The known device in question is perfectly symmetric, so that if a channel λi^* is injected through gate *b*, such a channel λi will be present on the output gate *c* together with the other channels *1...n* unaffected by a channel drop operation. In other words, in cross function, the channel to be extracted or injected passes from gate *a* to gate *d* or from gate *b* to gate *c*, while according to the bar function, all other channels (through channels) pass from gate *a* to gate *c* or from gate *b* to gate *d*.

[0019] By modifying the geometry of the phase shift stages, that is by modifying the relative delay of propagation that is introduced by the stages, the response characteristics of the device may be modified. Given the periodical form of the response characteristics of the device, it is possible to widen or narrow the interval of wavelength between two successive strongly attenuated wavelengths. In practice, if a broadening of this interval is desired, the relative delay introduced by the phase shift stages must be reduced, while by increasing said delay the interval is narrowed.

[0020] The number of "cells" composing the device, intending as an elementary cell the association of a phase shift stage with a relative directional coupler, that is the number of phase shift stages (SF) composing the device, has a direct influence on the attenuation characteristics of the device. More precisely, the attenuation in the interval comprised between two strongly attenuated wavelengths produced by the device is more uniform the larger the number of cells that compose the selective device.

[0021] For a deeper understanding of the functionality of a selective device suitable to implement channel adding and channel dropping functions, reference may be made to the article entitled: "Cascaded Coupler Mach-Zehnder Channel Dropping Filters for Wavelength - Division Multiplexed Optical Systems" by M. Kuznetsov, Journal of Lightwave Technology, Vol. 12, No. 2, February 1994.

[0022] For example, in the perspective of a European development project having as objective the realization of a high performance optical LAN, the development of a relatively low cost optical filter suitable to perform add/drop functions that can be fabricated according to available technologies, and which may be tuned on any wavelength selectable from a plurality of WDM wavelengths, is considered a basic requirement.

[0023] In developing a COBNET local network as mentioned above, the requisites of add/drop optical filters needed for equipping each node of the network may be defined as follows.

1) The add/drop filter must show an exceptionally low though loss ($L_{through}$) in view of the fact that this loss is sustained many times by the WDM signal circulating in the ring. The power budget must be calculated for the least privileged channel of the cascade of all the add/drop filters of the LAN. System's analysis show that by assuming a typical sensitivity of the receiver in the vicinity of -32dBm, the tolerable maximum value for $L_{through}$ is of about 5dB (for a four node ring) and of about 2.5dB (for an eight node ring).

2) In view of the fact that injection and extraction losses, L_{add} and L_{drop}, respectively, are sustained only once by the selected channel being subjected to the add/drop operations, the level of these losses is less critical and they may comfortably have a value similar to $L_{through}$.

3) The number of communication channels that may be managed by the system is typically much larger than the number of WDM wavelengths (for example, 32 communication channels may be managed with only eight WDM carrier wavelengths on each fiber of the ring).

These multiplexed communication channels may, in principle, have different bitrates as well as different format and power levels. The WDM combs at the input of the add/drop filters may therefore be heterogeneous.

Therefore optical crosstalk phenomena become particularly critical in these systems.

Each receiver is subject to the effect of several different crosstalk contributions, which may classified as of same wavelength (homowavelengh), when the interfering channels and the received channels have the same optical carrier wavelength, and of different wavelength (heterowavelength) in all the other instances. The signal/crosstalk ratio (SCR) in so-called "low end" (LE) receivers and in so-called "high end" (HE) receivers, evaluated on the base of crosstalk isolation coefficients of the add/drop filters: X_{bar} and X_{cross}, show that the most damaging contribution may be attributed to the crosstalk of same wavelength, as that generated by a high power channel that has just been injected on the channel of identical wavelength being extracted.

The large difference among respective powers of interfering channels and the large number of stations in which crosstalk phenomena may take place in certain transmission systems, may significantly depress the system's SCR ratio notwithstanding an apparently acceptable crosstalk coefficient of a single add/drop filter.

Exceptionally severe requirements are imposed therefore on design specifications of add/drop filters in order to assure that their spectral response will guarantee an X_{bar} coefficient (relevant to homowavelength crosstalk)

stage and η_{eff1} and η_{eff2} represent the effective refraction index of the medium of the two optical supports that constitute each phase-shift stage.

[0057] By considering that the invention contemplates a modification of the effective refraction index of the medium crossed by only one of the two optical supports (paths) by exploiting a thermo-optical effect or an electro-optical effect, it is evident that according to the invention, an extra phase delay of a predetermined value is introduced in only one optical path of the two paths of each phase-shift stage.

[0058] In other words, the invention contemplates that in addition to the effect of the geometric difference between the respective lengths of the optical paths, proper of an add/drop device of the type in question, a further phase shift be introduced by modifying the effective refraction index of the medium crossed by only one of the two optical paths of the phase-shift stage.

[0059] According to a preferred embodiment of the invention, the modification of the effective refraction index is performed by thermo-optical effect and to this end to one of the two waveguides that compose each phase-shift stage is associated a heater or heating strip.

[0060] These heaters may be driven in a voltage or in a current mode and they may be electrically connected in parallel or in series among each other and to either a controlled voltage generator or to a controlled current generator, through appropriate lead wires that may be bonded to the metal strips "integrated" in the device.

[0061] Patterned thin films of chromium, nickel-chromium alloys or of an equivalent metallic material that may be deposited by chemical vapor deposition techniques or by sputtering and patterned through a masking and etching step, may be used satisfactorily for realizing the tuning elements.

[0062] Integrated heaters may be in the form of patterned strips of a resistive metal of width in the order of 10 to 100 µm, length of about 2-3 mm and thickness of several hundreds nm.

[0063] The function of a tunable device of the invention of Fig. 5, functioning as a channel dropper from a WDM signal fed through the optical port P_0 is diagrammatically depicted in a in-tune condition in Fig. 6, showing its response peak (resonance peak) centered on the selected wavelength λ_j. The selected channel, corresponding to the wavelength λ_j, is available on the optical port P_2, while all the other deselected channels of the WDM signal are available on the optical port P_1 of the device.

[0064] A dual condition of operation of the same device, that is as a channel-adder for injecting a channel of wavelength λj^* in a WDM signal fed through the optical port P_0 of the device is depicted in Fig. 7. The signal λj^* injected through the optical port P_3 of the device adds itself to the plurality of WDM channels injected through the port P_0 and the totality of channels is available on the output port P_1 of the device.

[0065] According to a preferred embodiment depicted in Fig. 8, the device may be fabricated in an integrated form according to a so-called glass-on-silicon technology or by equivalent fabrication processes of integrated optical devices.

[0066] The tunability of the add/drop filter of the invention is preferably implemented by a thermo-optical mechanism.

[0067] According to this preferred embodiment, the tuning elements (arranged in electrical series in Fig. 8) may be patterned strips of a metallization film shown in the figure with the notation "heating strip", which may be photolithographically defined on the surface of the upper cladding dielectric material projectively over a portion of one of the two optical paths.

[0068] The patterning of a metallic heating strip may be such as to reproduce a profile substantially corresponding to a geometric projection of the straight arm waveguide portions (or alternatively of the curved arm portions) of the various phase-shift stages in cascade, so as to minimize thermal inertia effects.

[0069] Through the continuos metal line a current of a level suitable to provoke the raising of the temperature to a certain value may be forced in a precisely controlled manner.

[0070] According to a first embodiment, based on the exploitation of a thermo-optical effect, only a heating strip is used. According to a different embodiment, a Peltier cell is applied on the opposite face of the device juxtaposedly each heating strip. According to this alternative embodiment, the performance in terms of a more effective thermal dissipation and tuning times of the device is improved.

[0071] By employing a Peltier cell (not illustrated in the figures) on the face of the device opposite to the one on which the heater is disposed, it is possible to confine more precisely the heated zone in the vicinity of the portion of waveguide to be heated, by ensuring a "local" heat dissipation to prevent undesired propagation from the heater toward other portions of waveguide that should not be heated.

[0072] By recalling the fact that the tuning is based on the introduction of an offsetting delay on only one of the two optical paths that form the phase-shift stage, the heating must involve only one of the two optical waveguides.

[0073] The use of Peltier cells therefore facilitates the control of the thermal bias and optimization of tuning speed and stability.

[0074] Each fabricated device will possess an intrinsic thermal characteristic from which the operating temperature corresponding to a given resonance frequency may be derived. An appropriate bias current suitable to produce by Joule effect the heating of the waveguide to the correct tuning temperature of the filter for any given wavelength may therefore be readily established. Simple regulation systems of the bias signal, for example in the form of a current

forced through the various heating elements in series (or in parallel), functioning in an open loop or in a closed loop mode, are readily implementable and they can ensure the maintaining of a correct tuning temperature for any selected wavelength. Being these temperature control systems familiar to any technician with a normal knowledge of electronic control circuitry, a reiterated description of the many forms these circuits may assume is not deemed necessary for a full comprehension of the invention and of the manner in which it may be practiced. According to another embodiment of the invention, instead of a thermal optical effect an electro-optical effect may be employed for tuning the filter on a selected wavelength.

[0075] This alternative embodiment is schematically depicted in Fig. 9 and requires the realization of both optical paths or at least of the optical path whose refraction index must be modified for introducing the required extra phase shift, with a suitable polymer or with lithium niobate.

[0076] According to this alternative embodiment, the tuning element is a capacitor, a plate of which may be patterned in a similar way of a heating strip. The counterplate of the capacitor is preferably common to all the elements and constituted by a continuous metallization layer formed on the rear or bottom face of the integrated device.

[0077] Irrespectively of the mechanism exploited, the tunable filter of the invention lends itself to implement an automatic tuning system.

[0078] Accordingly, a special low frequency modulation could be imparted to each channel or carrier wavelength of the WDM signal besides its modulation with information carrying signals or, more simply, a low level and low frequency modulation may be imparted to the WDM signal though the filter itself.

[0079] A dedicated low frequency modulating signal as detected in a receiver may provide a DC level representative of the level of the demodulated and detected low frequency modulating signal usable by an appropriate tuning control loop for maintaining optimal tuning of the filter on the selected channel (λi).

[0080] Any known tuning optimization circuitry, adapted to the particular requirements of the add/drop filter of the invention, may be used for implementing an automatic functioning of the tunable filter of the invention.

[0081] A simplified block diagram of a tunable add/drop filter including an efficient tuning control system, according to an embodiment of this invention, is depicted in Fig. 10.

[0082] The closed loop tuning control system depicted in the figure exploits the tunable filter itself for introducing a low level, low frequency modulation on the WDM signal through a so-called "dithering" technique.

[0083] According to the embodiment shown, the tunable filter represented by the chain of alternately disposed phase shifting MZI and directional couplers, is supposed to be tunable on a selected channel λ_i by forcing a certain (that is of a known nominal level) current through heaters S, juxtaposed to the straight arm waveguide of the MZI stages, as schematically shown in the figure.

[0084] According to this embodiment, the selected channel λ_i being extracted through the drop port of the filter may be divided by a common splitter 5:95, in order to derive a small fraction of the light power of the channel, while the major portion (95%) is directed to a normal optical/electronic conversion circuitry of the optical receiver O_Rc. An eventually modified information may be reinjected in the WDM signal on the same channel λi^* through the add port of the add/drop filter. The derived fraction (≤5%) is also converted into an electrical signal, as schematized in the figure by the photodiode symbol at the output of which a first filter F1 is connected.

[0085] Periodically and for a short time, to the nominal biasing DC current generated by a dedicated bias generator BS is summed on the node SM a sinusoidal current of a fractionary amplitude (as compared to the level of the DC bias current produced by the bias generator), which is generated by a dither generator D_G. The frequency of the sinusoidal current may be generally equal or lower than 2kHz and chosen in function of the thermal inertial characteristics of the heating arrangement of the straight portions of the waveguides of the various MZI phase-shifting stages of the filter. This frequency may be as low as 100-200 Hz.

[0086] The superimposition of a sinusoidal current on the DC bias current produces an alternate shifting of the operating point of the filter in the neighborough of the selected wavelength (optical channel) onto which the filter should be perfectly tuned. This low frequency alternate shift (of relatively small amplitude in terms of frequency) of the operating point of the filter introduces a corresponding low frequency amplitude modulation on the WDM signal passing through the filter. Such a low frequency modulation will also be present on the dropped channel (λ_i). While the low frequency modulation will not materially disturb the demodulation and detection of the information carrying signals (of generally much higher frequency) in the optical receiver circuitry, this low frequency modulating sinusoidal signal is compared (in terms of difference of phase) with the original sinusoidal signal generated by the dither generator and the resulting error (phase) signal, preferably filtered though a passband filter F2 and suitably buffered, as shown in the diagram, is injected on the summation node SM. According to such a dithering technique, the phase of the reconstructed sinusoidal signal, compared by means of a unit CF with the phase of the original sinusoidal signal injected on the summation node SM by the dither generator, produces by means of a further filter F2 and an amplifier A an information representative of the actual point of operation of the tunable optical filter and therefore of an eventual need to increment or decrement the bias current, generated by means of a unit BS, to shift the resonance peak of the optical filter toward a lower wavelength or a higher wavelength. The tuning control loop circuit (not shown in the figure) may be such as

to nullify the phase error signal by suitably incrementing or decrementing the actual bias current to the tuning heaters S for the selected channel.

[0087] This dithering type of fine tuning adjustment can be carried out periodically to check and trim the tuning automatically, thus compensating for long term drifts of the preestablished tuning conditions of the filter. Therefore, the fine tuning intervention may be periodical and of short duration so that the low frequency modulation that is purposely imparted to the WDM signal is temporary and does not materially affect the transmission of information through the optical network.

Definition of the design parameters of the tunable filter of the invention

[0088] The definition of the three essential design parameters of a static selective device schematized in Fig. 11, is done by assuming that each cell of the device is composed of a phase-shift stage SF and a directional coupler AD, as shown in Fig. 12 and that therefore the entire filter is constituted by a chain of *k* phase-shift stages SF (typically interferometers based on the Mach-Zehnder principle or MZI stages) connected to each other by a number k+1 of directional optical couplers AD.

[0089] The phase shift due to thermo-optical effect on the straight part of the two unequal arms of a phase-shift stage, induced for example by employing a heating strip of length l_n, driven in a current mode, may be included in the matrix formulation:

$$T^i=\begin{bmatrix} e^{\frac{-j(\Phi+\phi^i-\Delta(T))}{2}} & 0 \\ 0 & e^{\frac{+j(\Phi+\phi^i-\Delta(T))}{2}} \end{bmatrix} \begin{bmatrix} \cos\Theta^i & j\,\mathrm{sen}\,\Theta^i \\ j\,\mathrm{sen}\,\Theta^i & \cos\Theta^i \end{bmatrix} \qquad (1)$$

where Θ^i is the coupling angle and $\Phi + \phi^i$ is the phase shift due to the unequal arm lengths of each MZI stage SF of the chain.

$\Delta(T)$ represents the phase shift contribution that depends on the temperature, controlled by the heater l_n of Fig. 12.

[0090] For a device composed of a number $k=5$ of stages, there will be also $k+1=6$ directional couplers, thus determining a transfer function that may be expressed by the following overall matrix:

$$T=\begin{bmatrix} \cos\Theta^0 & j\,\mathrm{sen}\,\Theta^0 \\ j\,\mathrm{sen}\,\Theta^0 & \cos\Theta^0 \end{bmatrix} \prod_{i=1}^{5} T^i \qquad (2)$$

T_{11} matrix elements correspond to the "bar" transfer characteristic (the optical signal paths of which are indicated with a dash line in the functional diagram of Fig. 11) while the matrix elements T_{12} correspond to the cross function (the optical signal paths of which are indicated with a continuous line in the functional diagram of Fig. 11).

[0091] The frequency transfer function can be expressed by the following Fourier series:

$$F(\omega)=\sum_{k=0}^{N} f_k e^{-jk\omega f_0^{-1}} \qquad (3)$$

where w is the relative optical angular frequency.

[0092] By replacing the term $e^{-j\omega f0-1}$ with a complex variable $z^{-1}{}_{l}$, the frequency response becomes a polynomial function with complex coefficients of the variable *z* in the *z*-plane:

$$F(z)=\sum_{k=0}^{N} f_k z^{-k} \qquad (4)$$

According to a preferred embodiment of the invention, instead of employing a classical tapered distribution of the couplers' strength, as proposed in the article: "Cascaded Coupler Mach-Zehnder Channel Dropping Filters for Wavelength - Division Multiplexed Optical Systems" by M. Kuznetsov, Journal of Lightwave Technology, Vol. 12, No. 2, February 1994, or a Chebychev distribution of the f_k coefficients of the polynomial function (real positive coefficients) for suppressing sidelobes responsible of incoherent crosstalk at off-resonance wavelengths, a desired frequency response is selected and such a frequency response is expressed in a Fourier series. A superimposition in the plane of the z transform is then operated with said preselected response characteristic by employing a polynomial of a predefined order, corresponding to the number k of stages that are intended to be used for implementing the static filter.

[0093] The method of the invention, by allowing during the design stage to account for the effects on the spectral behavior of the sidelobes contribution to the cross response characteristic according to design criteria of Chebychev electronic filters while preserving a substantially flat cross response characteristic, "substantially free of ripple", gives outstanding advantages if compared with the above mentioned known design approaches.

[0094] Since the spectral position of a given WDM channel is fixed by the transmission system's specifications, the polynomial of k order in the domain of the z transform may be optimized in order to produce its respective zeroes of the cross transfer function substantially coincident with the spectral position of the channel. This permits to fulfil the requirements related to heterowavelength crosstalk with a reduced number (k) of cells (or MZI stages).

[0095] According to this design approach of the selective static device of the Invention, though requiring the realization of at least a phase-shift stage of the device with a difference of optical paths different from that of the other phase-shift stages, has been surprisingly found that an exceptionally flat cross response characteristic can be achieved, capable of fulfilling even the most stringent homowavelength crosstalk specifications for the channel that must be injected or extracted through the device of the invention.

[0096] The phase-shift stage with an optical path difference different from that of all the other phase-shift stages composing the add/drop tunable filter of the invention, may irrespectively be the first one or the second of the sequence of phase-shift stages, starting from the port defined as the "add" port. In presence of nonnegligible losses, the filter of the invention may be regarded as an asymmetric structure, therefore the add port will be univocally defined and similarly univocally defined will also be the "drop" port.

[0097] The difference between the two optical paths of such a phase-shift stage (the first or the second) of the sequence, different from all the other phase-shift stages, may be indifferently greater or smaller than the difference of optical paths of the other phase-shift stages and must be intrinsically bi-directional as to cause a phase shift angle smaller or greater by π than the phase shift angle that is introduced by all the other phase-shift stages of the filter.

[0098] This requirement of one or the first two cells (phase-shift stages) of the filter is instrumental in ensuring an outstandingly flat passband characteristic, essentially free of ripple.

[0099] The characteristics of the $k+1$ directional couplers (AD) are then optimized in function of the relative coefficients of the terms of the Fourier expansion series in order to improve the selectivity of the filter. Such an optimization differently from what occurs when employing a tapered distribution or a Chebychev distribution as in prior art approaches, has a practically negligible consequence in terms of increasing the ripple of the passband characteristic.

[0100] Therefore the selective static device of the invention is perfectly optimized also in terms of homowavelength crosstalk, though employing a considerably reduced number of stages, thus minimizing the power budged.

[0101] Operatively, after having derived the polynomial in function of the complex variable z, the parameters θ^j and ϕ^j may be extracted from the equation (4).

[0102] The unknown parameters θ^j and ϕ^j must verify the following conditions:

$$\sum_{k=0}^{N+1} \Theta_i(f_o) = \frac{\pi}{2} - \delta_{phaseangle} \qquad (5)$$

$$\Delta L_{geom} = m \cdot \lambda_{guided} = (m \pm \pi)\lambda_{guided} \qquad (6)$$

$$FSR(f_o) = \frac{c}{n_g(f_o) \cdot m\lambda_{guided}} \qquad (7)$$

where m is the order of the Mach-Zehnder interferometers that is of the phase-shift stages SF employed, n_g is the group index and c is the speed of light in vacuum. The phase shift by π must be introduced in an effective way along the sequence of cells in order to verify the condition (5) for a desired FWHM/FSR ratio and in respect of the position of the zeroes in the band of the channels that must or must not be extracted and of the chosen level of the sidelobes.

The $\delta_{phase\ angle}$ may be considered at worst to be equal or less than 5% of $\pi/2$ on account of the fabrication process spread and of the spread in the tuning bias values.

[0103] The thermo-optical tuning may be effected by driving electrical heaters arranged in proximity of the straight arm of each phase-shift stage SF, in such a way as to introduce an identical incremental relative phase delay between the two paths of different length of all the Mach-Zehnder stages, by causing a local variation of the refraction index of the heated portion of waveguide.

[0104] The frequency response of such a filter is tuned by varying the temperature to which the straight portion of waveguide of the various phase-shift stages SF is heated. For waveguides made of silicon oxide (SiO_2), such a dynamically introduced phase shift is given by the following equation:

$$\Delta(T) = \frac{2\pi}{\lambda}\frac{\partial n_{SiO_2}}{\partial T} l_s \Delta T \qquad (8)$$

[0105] The thermal conductivity of silica n_{SiO2} is in the order of $11.5\mu k^{-1}$ and l_s is the length of the heating strip of metallic material.

EXAMPLE 1

[0106] A tunable *"1-from-4"* add/drop filter based on the principle of a resonating optical coupler has been realized in accordance with the present invention.

[0107] The functional diagram of the device is schematically reproduced in Fig. 11, while each single cell of the interferometric device is depicted in Fig. 12.

[0108] One of the four wavelengths managed by the tunable device, present on the *through* input P1 port is directed to the *drop* output *(Cross* P4 port), while the other three wavelengths are directed to the *through* output port *(Bar* P2 port). Simultaneously, a local transmitter introduces a channel on a second input port (*Bar* P3 port) having the same carrier wavelength of the channel that is directed toward the *drop* output port (*Cross* P4 port), directing it to the second *through* output port (*Cross* P2 port).

[0109] An overall layout of the device is depicted in Fig. 13.

[0110] The device has been realized in a so-called "Glass-on-Silicon" technology with a lower cladding layer of phosphorus doped SiO_2 having a thickness of $12\mu m$, a waveguide of 8% phosphorus doped SiO_2 having dimensions $6.5*5.5\mu m$ and with an upper cladding layer of boron and phosphorus doped SiO_2 with a thickness of $15\mu m$.

[0111] All the layers were deposited by chemical deposition from vapor phase conducted at low pressure (LPCVD) and each deposited film was annealed at a temperature of about 1000°C to reduce stresses in the waveguide and to reduce losses.

[0112] The heaters l_1, l_2, ... and l_5, are patterned chromium strips of $0.25*10\mu m$ while the current distributing buses are of patterned gold strips of $0.5*300\mu m$, driven in a voltage mode (the driving mode being optional and may be chosen so as to optimize system's voltage and current requisites for controlling the tunable filter).

[0113] The f_k coefficients of the Fourier expansion series (4) in the complex z plane for $k=0, ..., 5$, were calculated so as to approximate as much as possible the desired frequency response. The order m of the phase shifters (Mach-Zehnder interferometers or MZI) was chosen to be $m=119$.

[0114] The order m of the phase-shift stages, expressed as a whole number of the difference of guided wavelength optical paths between the two arms of each Mach-Zehnder interferometer, corresponded to a designed free spectral range (FSR) of the four-channel device of *12.8nm*, with a separation distance among channels of *3.2nm*.

[0115] The real dimensions of the chip were of *80*3nm*.

[0116] The differences of optical path ΔL and the relative phase shift angles ϕ of the five Mach-Zehnder stages of the device were the following:

$$\Delta L_1=\lambda g*m \qquad \phi_1=0$$

$$\Delta L_2=\lambda g*(m+\pi/2\pi) \qquad \phi_2=\pi$$

$$\Delta L_3=\Delta L_1 \qquad \phi_3=0$$

$$\Delta L_4=\Delta L_1 \qquad \phi_4=0$$

$$\Delta L_5=\Delta L_1 \qquad \phi_5=0$$

λ_g representing the guided wavelength corresponding to the design wavelength λ_p according to the relationship $\lambda_g=\lambda_p/\eta_{eff(\lambda p)}$, wherein $\eta_{eff(\lambda p)}$ corresponds to the effective refraction index of the medium with which the waveguide is made, at the design wavelength λ_p.

[0117] Measurements were effected by using a tunable laser and light was coupled through a standard unimodal fiber, aligned and butt coupled to the relevant input port, using an index matching oil according to common coupling techniques, while a coupling fiber to a power meter was aligned butt coupled to the relevant output port. A microprocessor controlled the laser, performing a wavelength scan and acquiring the relative power spectrum.

[0118] The tests were conducted by scanning the entire Free Spectral Range (FSR) of the filter by *50pn* increments for a total of *361* acquired points for each scan.

[0119] The complete cross response diagram is shown in Fig. 14, while the *3dB* cross response is shown in Fig. 15.

[0120] As may be observed, a bandwidth (FWHM) of *3.76nm* has been obtained.

[0121] The insertion loss measured on a reference sample of single Mach-Zehnder stage having the same curvature radius of those used for realizing the phase-shift stages of the integrated device of the invention, was determined to be in the vicinity of *-1.8dB*.

[0122] A corresponding loss for a straight waveguide of *8cm* was measured to be of *0.250dB* at *1550nm* showing that the fiber-to-waveguide coupling was the dominant loss mechanism.

[0123] For comparison purposes, the responses measured and the design ones are shown in Figures 16 and 17. The characteristics show an outstanding superimposition. In particular the SFR obtained coincides with the design one.

[0124] The crosstalk coefficient on the extracted channel (X_{bar}) is of *-18dB* (Fig. 16), while the crosstalk coefficient on the through channels (X_{cross}) is of *-14dB.*

[0125] A measured FWHM of *400GHz* may be read from the diagram of Fig. 17, which is in good agreement with the design value and which may reasonably be improved further by reducing the losses and the coupling length.

[0126] The tunability of the filter through thermo-optical mechanism has been verified for the whole FSR.

[0127] Fig. 18 shows the shift of the response characteristics obtained with a regulation ratio of about 2V/nm

EXAMPLE 2

[0128] A second prototype filter has been realized by using the same fabrication techniques and the same technological parameters used in the Example 1, but inverting the relative dimensioning of the first two Mach-Zehnder interferometers so as to correspond to the following architecture parameters:

$$\Delta L_1=\lambda g^*(m+\pi/2\pi) \qquad \phi_1=\pi$$

$$\Delta L_2=\lambda g^*m \qquad \phi_2=0$$

$$\Delta L_3=\Delta L_2 \qquad \phi_3=0$$

$$\Delta L_4=\Delta L_2 \qquad \phi_4=0$$

[0129] The response characteristics of this second prototype are substantially superimposable in terms of FWHM to those of the prototype of Example 1, thus demonstrating the possibility of obtaining the same FWHM with a different position of the MZI stage of different phase shift, which need to be such as to optimize the FWHM/FSR ratio and the secondary lobes (or sidelobes) level in a strict correlation between each other.

[0130] According to an important further aspect of the invention, several tunable devices may be interconnected in a loop arrangement to implement add/drop functions for an incremented number of channels or carrier wavelength, without substantially incrementing the insertion losses ($L_{through}$).

[0131] Fig. 19 shows a functional diagram of an *"1-from-8"* add/drop device composed by two structures connected in a loop configuration: a first structure composed of four phase-shift Mach-Zehnder interferometer stages: SF1, SF2, ...

and SF4, and a second structure composed of two phase-shift Mach-Zehnder interferometer stages: SF5 and SF6, AD1, ...AD8 being the respective directional couplers that compose the modular *"1-from-8"* filter.

[0132] The advantage of a modular architecture as the one depicted in Fig. 19 is represented by the fact that the *through* or pass channels are subject to insertion losses ($L_{through}$) corresponding to the losses attributable to the passage of the optical signals through the four cells of the first structure, while only the injected and extracted channel is subject to losses corresponding to the passage through the four cells of the first structure and through the two cells of the second structure looped to the first one.

[0133] Of course, the electrical buses 1 and 2 for applying a biasing voltage signal to the tuning elements S of the tuning control system may be advantageously common to the two structures.

[0134] The periodic nature of the add/drop filter of the invention may be exploited to design an add/drop optical filter capable of injecting and/or extracting selectable pairs of channels (carriers wavelength) of the WDM signal, by appropriately designing the spectral distance between the periodic reason peaks of the response characteristics of the filter.

[0135] Figures 20 and 21 show the basic diagram of a *"2-from-8"* add/drop device (a six port device) derived from a *"1-from-8"* add/drop architecture including two distinct structures: *"1-from-4"* and *"1-from-2"*.

[0136] According to this sample implementation, a selectable pair of channels (in the example λ_1* and λ_5*) are being injected through the add port P8 of the tunable filter *1-from-4* structure, through a common 2:1 coupler, by applying the two optical wavelengths at the input ports P6 and P5 of the coupler.

[0137] The same selected pair of channels λ_1 and λ_5, will be present on the "drop port" 7 of the first *1-from-4* structure and the respective channels λ_1 and λ_5 will be present at the output ports P4 and P3 of the *1-from-2* structure. The WDM signal containing all eight channels ($\lambda_1 \ldots \lambda_5 \ldots \lambda_8$) fed through the port P1 of the *1-from-4* structure will be present as ($\lambda_1^*, \lambda_2 \ldots \lambda_5^* \ldots \lambda_8$) at the output port P2 of the *1-from-4* structure.

[0138] The integration layout is simplified because of the relative containment of the overall length of the chip, which is a nonnegligible aspect for developing tunable add/drop integrated devices capable of managing an increasing number of channels or carrier wavelengths.

[0139] Notwithstanding the fact that the description and the figures referred to preferred embodiments, the invention should not be considered limited to these preferred embodiments but may be implemented also in different forms as a technician will from time to time chose to adopt to best suit his design needs.

[0140] As already mentioned, a possible variation is that of exploiting an electro-optical mechanism, either per se or in cooperation with a thermo-optical mechanism for tuning the add/drop filter of the invention, by employing waveguides of a polymer or of lithium niobate that are materials known to be susceptible to a marked electro-optical effect besides to a thermo-optical effect. It is also possible to obtain a plurality of looped or linear structures connecting together a different number of elementary structures, so as to obtain a 1-from-8 add/drop filter, a 2-from- 8 add/drop filter or add/drop filters with features different by the above disclosed 1-from-8 or 2-from-8 filters.

Claims

1. Tunable add/drop optical device adapted to handle wavelength division multiplexed (WDM) signals, for injecting or extracting, i.e. add/drop, at least a selected optical channel or carrier wavelength in or from a set of multiplexed channels or carriers of different wavelength, comprising a plurality of directional couplers (AD_1,...,AD_6) and a plurality of phase-shift stages (SF_1,...,SF_5), alternately connected in cascade, wherein each phase-shift stage defines a certain optical path length difference (ΔL_1,...,ΔL_5) between two distinct optical paths of the stage, causing a periodic response characteristic with a spectral separation between two adjacent peaks of said periodic response characteristic sufficient to contain all deselected wavelengths of said multiplexed channels when a peak of the periodic response characteristic is centered on a selected wavelength, the optical medium of one of said two distinct optical paths of each of said phase-shift stages having a refraction index dependent from a physical parameter belonging to the group composed of temperature and electric field intensity and biasing means (L_1,...L_5) for controllably varying said parameter, **characterized in that**

   two consecutive phase-shift stages (SF_1,...SF_5) of said plurality of phase-shift stages have differences of length of their two optical paths different from each other and in a preestablished ratio while all the remaining phase-shift stages (SF_3,...,SF_5) have differences of length of their two optical paths identical and equal to that of one of said two consecutive stages; and

   said directional couplers, alternately disposed among said phase-shift stages, have coupling angles independently designed as fractional values of their sum that is equivalent in module to $\pi/2$.

2. The device according to claim 1, wherein said optical path length 'differences and said coupling angles of said cascade correspond to coupling angles and phase shift angles derived from a Fourier series expansion polynomial of predefined order corresponding to the number of phase-shit stages of the device, of a predefined frequency

transfer function of the device.

3. The device according to claim 2, wherein the derived values of the phase shift and coupling angle parameters of said pluralities of stages produce a zero of said transfer function coincident with the carrier wavelength of a selected channel.

4. The device according to claim 1, **characterized by** being implemented in an integrated form, said physical parameters being temperature and said means comprising Joule effect heating strips of a resistive metal defined on the surface of an upper cladding dielectric layer in coincidence with the geometric projection of a straight portion of optical waveguide of each of said phase-shift stages.

5. The device according to claim 1, wherein said physical parameter is electric field intensity and said means comprise first metallic field plates defined on the surface of an upper cladding dielectric layer in coincidence with the geometric projection of a straight portion of waveguide of said phase-shift stages and by a second common field plate in the form of a continuous metallization on the bottom face of the integrated device.

6. The device according to claim 4, wherein the material of said straight portion of waveguide of each phase-shift stage is of phosphorus doped silica glass.

7. The device according to claim 4 or 5, wherein the material of said straight portion of waveguide is a polymer.

8. The device of claim 5, wherein the material of said straight portion of waveguide of each phase-shift stage is lithium niobate.

9. The device according to claims 4, 6 or 7, wherein each of said heating strips of resistive metal is driven in a voltage or in a current mode and has a length of several millimeters and a width of several tens of micrometers and a thickness in the order of several hundreds of nanometers.

10. The device of claim 6, **characterized by** comprising a Peltier cells disposed on the bottom face of the integrated device, juxtaposed to each heating strip defined on the upper cladding of the heated portion of waveguide.

11. The device according to claim 1, wherein said metal heating strip is driven in an open loop mode.

12. The device according to claim 1, wherein said heating strip is driven in a closed loop mode.

13. The device according to claims 4 or 6, wherein said resistive metallic material is chromium or an alloy of nickel-chromium.

14. The device according to claim 1, **characterized by** including dithering means to impart a low frequency modulation on the WDM signal by superimposing a sinusoidal contribution on a DC bias signal of said means for controllably varying said parameter, generating an error signal representative of the offset of the response peak form an ideal alignment with the selected wavelength.

15. The device according to any of the preceding claims **characterized by** including two structures composed by a different number of phase shift stages and directional couplers alternately connected in cascade, looped together into a four port coupling device.

16. The device according to claim 15, wherein the first structure includes four phase shift stages and five directional couplers, the second structure comprises two phase shift stages and three directional couplers, forming together a 1-from-8 add/drop filter.

17. The device according to any one of claims 1 to 14, **characterized by** including at' least three structures composed by a different number of phase shift stages and directional couplers alternately connected in cascade, wherein the first structure includes four phase shift stages and five directional couplers, the second structure comprises two phase shift stages and three directional couplers, the third structure comprises a coupler, forming together a 2-from-8 add/drop filter.

Patentansprüche

1. Abstimmbare optische Einfüge-/Ausblendvorrichtung, die zum Umgehen mit Wellenlängen-Multiplex(WDM)-Signalen angepasst ist, zum Einführen oder Abziehen, d.h. Einfügen/Ausblenden, mindestens einer ausgewählten optischen Kanal- oder Trägerwellenlänge in einen oder aus einem Satz von Multiplex-Kanälen oder -Trägern unterschiedlicher Wellenlänge, umfassend eine Mehrzahl von Richtkopplern (AD1, ..., AD6) und eine Mehrzahl von Phasenverschiebungsstufen (SF1, ..., SF5), die abwechselnd in Kaskade geschaltet sind, wobei jede Phasenverschiebungsstufe einen bestimmten Längenunterschied des optischen Wegs (ΔL1, ..., ΔL5) zwischen zwei unterschiedlichen optischen Wegen der Stufe definiert, was zu einer periodischen Ansprechcharakteristik mit einer spektralen Trennung zwischen zwei benachbarten Spitzen der periodischen Ansprechcharakteristik führt, die ausreicht, um alle inaktivierten Wellenlängen der Multiplexkanäle zu enthalten, wenn eine Spitze der periodischen Ansprechcharakteristik auf einer ausgewählten Wellenlänge zentriert ist, wobei das optische Medium einer der beiden unterschiedlichen optischen Wege von jedem der Phasenverschiebungsstufen einen Brechungsindex, der von einem physikalischen Parameter abhängt, der zur aus Temperatur und elektrischer Feldstärke gebildeten Gruppe gehört, und eine Vorspanneinrichtung (L1, ..., L5) zum verstellbaren Variieren der Parameter aufweist, **dadurch gekennzeichnet, dass** zwei aufeinanderfolgende Phasenverschiebungsstufen (SF1, ..., SF5) aus der Mehrzahl der Phasenverschiebungsstufen Längenunterschiede bezüglich ihrer beiden optischen, sich voneinander in einem vorbestimmten Verhältnis unterscheidenden Wege aufweisen, während alle übrigen Phasenverschiebungsstufen (SF1, ..., SF5) Längenunterschiede bezüglich ihrer beiden optischen Wege aufweisen, die mit dem von einem der beiden aufeinanderfolgenden Stufen identisch und gleich sind; und
die Richtkoppler, die sich abwechselnd zwischen den Phasenverschiebungsstufen befinden, Koppelwinkel haben, die unabhängig voneinander als Bruchwerte ihrer im Modul $\pi/2$ entsprechenden Summe angelegt sind.

2. Vorrichtung nach Anspruch 1, wobei die Längenunterschiede des optischen Wegs und die Koppelwinkel der Kaskade den Koppelwinkeln und Phasenverschiebungswinkeln entsprechen, die von einer Fourier-Reihen-Expansionspolynomen vorbestimmter Größenordnung abgeleitet sind, die der Anzahl der Phasenverschiebungstufen der Vorrichtung von einer vorbestimmten Frequenzübertragungsfunktion der Vorrichtung entspricht.

3. Vorrichtung nach Anspruch 2, wobei die abgeleiteten Werte der Phasenverschiebung und die Koppelwinkelparameter der Mehrzahlen von Stufen einen Nullwert der Übertragungsfunktion erzeugen, der mit der Trägerwellenlänge eines ausgewählten Kanals zusammenfällt.

4. Vorrichtung nach Anspruch 1, **dadurch gekennzeichnet, dass** sie in integrierter Form umgesetzt wird, wobei die physikalischen Parameter die Temperatur ist und die Einrichtungen Joule-Effekt-Heizstreifen eines Widerstandsmetalls umfassen, das auf der Oberfläche einer oberen dielektrischen Überzugsschicht in Übereinstimmung mit der geometrischen Projektion eines geraden Abschnitts des optischen Hohlleiters von jeder der Phasenverschiebungsstufen festgelegt ist.

5. Vorrichtung nach Anspruch 1, wobei der physikalische Parameter die elektrische Feldstärke ist und die Einrichtungen erste metallische Feldplatten umfassen, die auf der Oberfläche einer oberen dielektrischen Überzugsschicht in Übereinstimmung mit der geometrischen Projektion eines geraden Teils des Hohlleiters der Phasenverschiebungsstufen und durch eine zweite gemeinsame Feldplatte in Form einer durchgehenden Metallisierung auf der Unterseite der integrierten Vorrichtung festgelegt sind.

6. Vorrichtung nach Anspruch 4, wobei das Material des geraden Abschnitts des Hohlleiters jeder Phasenverschiebungsstufe aus phosphordotiertem Siliziumdioxidglas besteht.

7. Vorrichtung nach Anspruch 4 oder 5, wobei das Material des geraden Abschnitts des Hohlleiters ein Polymer ist.

8. Vorrichtung nach Anspruch 5, wobei das Material des geraden Abschnitts des Hohlleiters jeder Phasenverschiebungsstufe Lithiumniobat ist.

9. Vorrichtung nach Anspruch 4, 6 oder 7, wobei jeder der Heizstreifen aus Widerstandsmetall in einem Spannungsoder in einem Strommodus angesteuert wird und eine Länge von mehreren Millimetern und eine Breite von mehreren Zehntel Mikrometern sowie eine Dicke in der Größenordnung von mehreren Hundertstel Nanometern aufweist.

10. Vorrichtung nach Anspruch 6, **dadurch gekennzeichnet, dass** sie Peltier-Zellen umfasst, die auf der Unterseite

der integrierten Vorrichtung vorgesehen sind, und zwar neben jedem Heizstreifen, der auf dem oberen Überzug des Heizabschnitts des Hohlleiters festgelegt ist.

11. Vorrichtung nach Anspruch 1, wobei der Metallheizstreifen in einem Open-loop-Modus angesteuert ist.

12. Vorrichtung nach Anspruch 1, wobei der Heizstreifen in einem Closed-loop-Modus angesteuert ist.

13. Vorrichtung nach Anspruch 4 oder 6, wobei das metallische Widerstandsmaterial Chrom oder eine Legierung aus Nickel-Chrom ist.

14. Vorrichtung nach Anspruch 1, **dadurch gekennzeichnet, dass** sie Rasterungseinrichtungen aufweist, um dem WDM-Signal eine niedrige Frequenzmodulation durch Überlagern eines sinusförmigen Beitrags zu einem Gleichstrom-Vorspannungssignal der Einrichtung zum steuerbaren Variieren des Parameters, Erzeugen eines Fehlersignals, das den Versatz der Ansprechspitzen von einer idealen Ausrichtung mit der ausgewählten Wellenlänge darstellt, zu verleihen.

15. Vorrichtung nach einem der vorhergehenden Ansprüche, **dadurch gekennzeichnet, dass** sie zwei Aufbauten aufweist, die aus einer unterschiedlichen Anzahl von Phasenverschiebungsstufen und Richtkopplern gebildet ist, die abwechselnd in Kaskade geschaltet sind, die miteinander zu einer Vier-Port-Koppelvorrichtung zusammengeschlossen sind.

16. Vorrichtung nach Anspruch 15, wobei der erste Aufbau vier Phasenverschiebungsstufen und fünf Richtkoppler aufweist, der zweite Aufbau zwei Phasenverschiebungsstufen und drei Richtkoppler umfasst, die zusammen einen 1-aus-8 Einfüge/Ausblend-Filter bilden.

17. Vorrichtung nach einem der Ansprüche 1 bis 14, **dadurch gekennzeichnet, dass** sie mindestens drei Aufbauten aufweist, die durch eine unterschiedliche Anzahl von Phasenverschiebungsstufen und Richtkopplern gebildet ist, die abwechselnd in Kaskade geschaltet sind, wobei der erste Aufbau vier Phasenverschiebungsstufen und fünf Richtkoppler aufweist, der zweite Aufbau zwei Phasenverschiebungsstufen und drei Richtkoppler umfasst, der dritte Aufbau einen Koppler umfasst, die zusammen einen 2-aus-8 Einfüge/Ausblend-Filter bilden.

Revendications

1. Dispositif optique d'insertion/extraction accordable conçu pour traiter des signaux multiplexés en longueur d'onde, destiné à insérer/extraire (insertion/extraction) au moins un canal optique sélectionné ou une longueur d'onde porteuse sélectionnée, dans ou depuis un ensemble de canaux ou de porteuses optiques multiplexés de longueurs d'onde différentes, comprenant une pluralité de coupleurs directionnels (AD1,..., AD6) et une pluralité d'étages à décalage de phasage (SF1,..., SF5), raccordés alternativement en cascade, dans lequel chaque étage à décalage de déphasage définit une certaine différence de longueur de chemin optique (ΔL1,..., ΔL5) entre les deux chemins optiques distincts de l'étage, ce qui entraîne une réponse caractéristique périodique avec une séparation spectrale entre deux pics adjacents de ladite réponse caractéristique périodique suffisante pour contenir toutes les longueurs d'onde désélectionnées desdits canaux multiplexés lorsqu'un pic de réponse caractéristique périodique est centré sur une longueur d'onde sélectionnée, le support optique d'un desdits deux chemins optiques distincts de chaque étage à décalage de phasage présentant un indice de réfraction dépendant d'un paramètre physique appartenant au groupe constitué par la température et l'intensité du champ électrique et des moyens de polarisation (L1,...,L5) pour faire varier, en pouvant le régler, ledit paramètre, **caractérisé en ce que** :

   les deux étages à décalage de phase successifs (SF1, SF5) de ladite pluralité d'étages à décalage de phase présentent des différences de longueur de leurs deux chemins optiques différentes l'une de l'autre et selon un rapport préétabli, tandis que tous les étages de déphasage restants (SF1,...,SF5) présentent des différences de longueur de leurs deux chemins optiques identiques et égales à celle de la longueur desdits deux étages successifs ; et
   lesdits coupleurs directionnels, disposés alternativement parmi lesdits étages à décalage de phase, ont des angles de couplage désignés de façon indépendante en tant que valeurs fractionnelles de leur somme, ce qui équivaut, en module, à $\pi/2$.

2. Dispositif selon la revendication 1, dans lequel lesdites différences de longueur du chemin optique de ladite cas-

cade correspondent aux angles de couplage et aux angles de décalage de phase d'une fonction polynomiale de développement en série de Fourier d'un ordre prédéfini correspondant au nombre d'étages à décalage de phase du dispositif, et une fonction de transfert de fréquence prédéfinie du dispositif.

3. Dispositif selon la revendication 2, dans lequel les valeurs dérivées du décalage de phase et les paramètres de l'angle de couplage desdites pluralités d'étages produisent un zéro de ladite fonction de transfert correspondant à la longueur d'onde de la porteuse d'un canal sélectionné.

4. Dispositif selon la revendication 1, **caractérisé en ce qu'**il est mis en oeuvre sous forme intégrée, lesdits paramètres physiques étant la température et lesdits moyens comprenant des bandes chauffantes à effet Joule en métal résistif définies sur la surface d'une couche diélectrique de gaine supérieure correspondant à la projection géométrique d'une partie droite d'un guide d'onde optique de chacun desdits étages à décalage de phase.

5. Dispositif selon la revendication 1, dans lequel ledit paramètre physique est l'intensité du champ électrique et lesdits moyens comprennent des plaques de champ métalliques définies sur la surface d'une couche diélectrique de gaine supérieure correspondant à la projection géométrique de la partie droite du guide d'onde desdits étages de déphasage et par une seconde plaque de champ commune se présentant sous la forme d'une métallisation continue sur la face inférieure du dispositif intégré.

6. Dispositif selon la revendication 4, dans lequel le matériau de ladite partie droite de chaque étage de déphasage est constitué de verre de silice dopée au phosphore.

7. Dispositif selon la revendication 4 ou 5, dans lequel le matériau de ladite partie droite du guide d'ondes est un polymère.

8. Dispositif selon la revendication 5, dans lequel le matériau de la partie droite du guide d'ondes de chaque étage à décalage de phase est du niobate de lithium.

9. Dispositif selon la revendication 4, 6 ou 7, dans lequel chacune desdites bandes chauffantes en métal résistif est commandée en tension ou en courant ou et présente une longueur de quelques millimètres et une largeur de quelques dizaines de micromètres et une épaisseur de l'ordre de quelques centaines de nanomètres.

10. Dispositif selon la revendication 6, **caractérisé en ce qu'**il comprend des cellules Peltier disposées sur la face inférieure du dispositif intégré, juxtaposé à chaque bande chauffante sur la gaine supérieure de la partie chauffée du guide d'onde.

11. Dispositif selon la revendication 1, dans lequel ladite bande chauffante métallique est commandée dans un mode en boucle ouverte.

12. Dispositif selon la revendication 1, dans lequel ladite bande chauffante est commandé dans un mode en boucle fermée.

13. Dispositif selon les revendications 4 ou 6, dans lequel ledit matériau métallique résistif est du chrome ou un alliage nickel/chrome.

14. Dispositif selon la revendication 1, **caractérisé en ce qu'**il comprend des moyens d'activation destinés à affecter une modulation basse fréquence au signal multiplexé en longueur d'onde, en superposant une contribution sinusoïdale à un signal de polarisation en courant continu desdits moyens destinés à faire varier, en pouvant le régler, ledit paramètre, en générant un signal d'erreur représentatif du décalage du pic de réponse par rapport à un alignement idéal avec la longueur d'onde sélectionnée.

15. Dispositif selon l'une quelconque des revendications précédentes, **caractérisé en ce qu'**il comprend deux structures constituées d'un nombre différent d'étages à décalage de phase et de coupleurs directionnels qui sont alternativement raccordés en cascade, réunis en boucle pour former un dispositif de couplage à quatre accès.

16. Dispositif selon la revendication 15, **caractérisé en ce que** la première structure comprend quatre étages à décalage de phase et cinq coupleurs directionnels, la deuxième structure comprend deux étages à décalage de phase et trois coupleurs directionnels, ce qui forme un filtre d'insertion/extraction 1 sur 8.

17. Dispositif selon l'une quelconque des revendications 1 à 14, **caractérisé en ce qu'**il comprend au moins trois structures constituées d'un nombre différent d'étages à décalage de phase et de coupleurs directionnels alternativement raccordés en cascade, dans lequel la première structure comprend quatre étages à décalage de phase et cinq coupleurs directionnels, la deuxième structure comprend deux étages à décalage de phase et trois coupleurs directionnels, la troisième structure comprend un coupleur, ce qui forme un filtre d'insertion/extraction 2 sur 8.

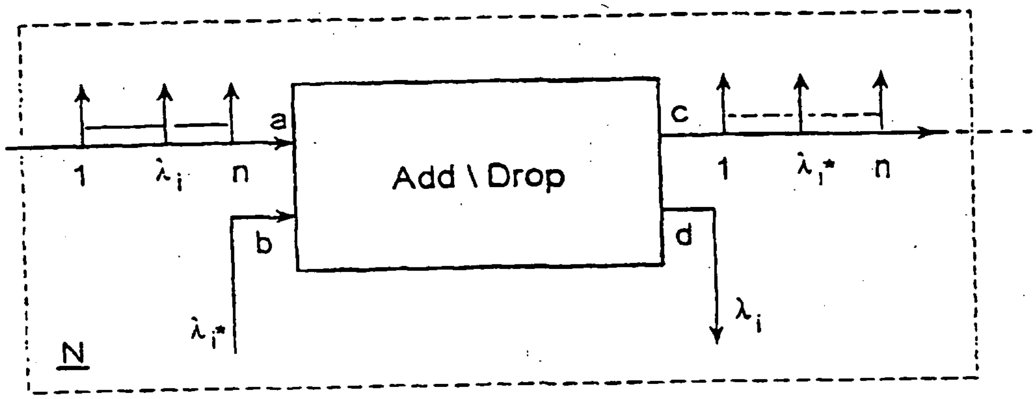

a
1
λ_i
n
Add \ Drop
c
1
λ_{i^*}
n
b
d
λ_{i^*}
λ_i
N

Fig. 1

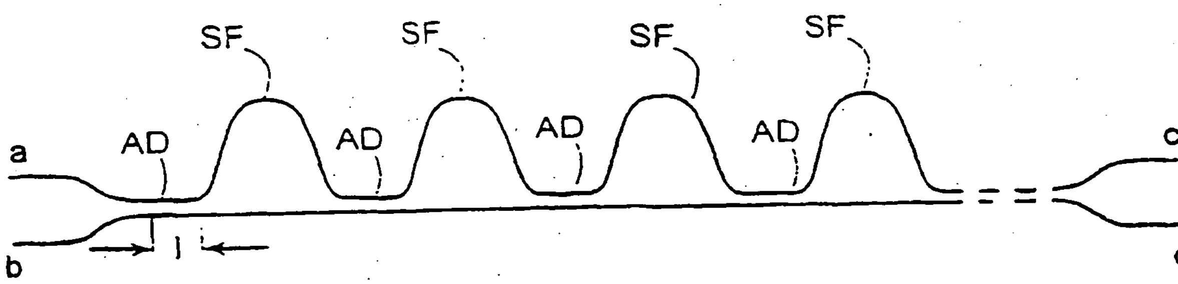

SF
SF
SF
SF
a
AD
AD
AD
AD
c
b
l
d

Fig. 2

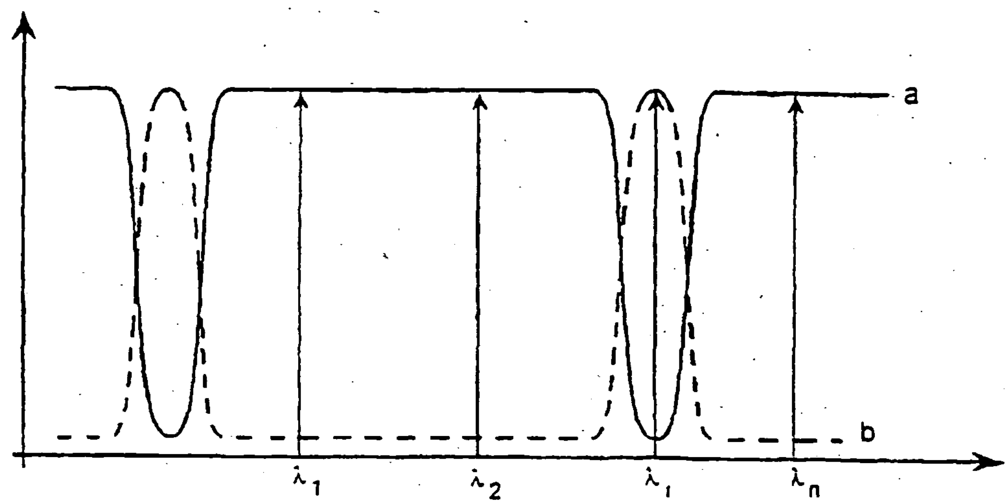

a
b
λ1
λ2
λi
λn

Fig. 3

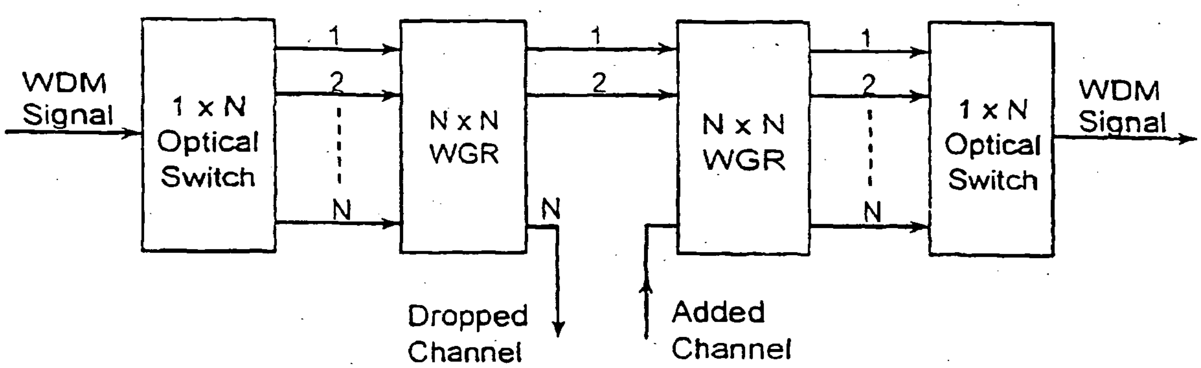

WDM Signal
1 x N Optical Switch
1
2
N
N x N WGR
N
Dropped Channel
Added Channel
N x N WGR
1 x N Optical Switch
WDM Signal

Fig. 4

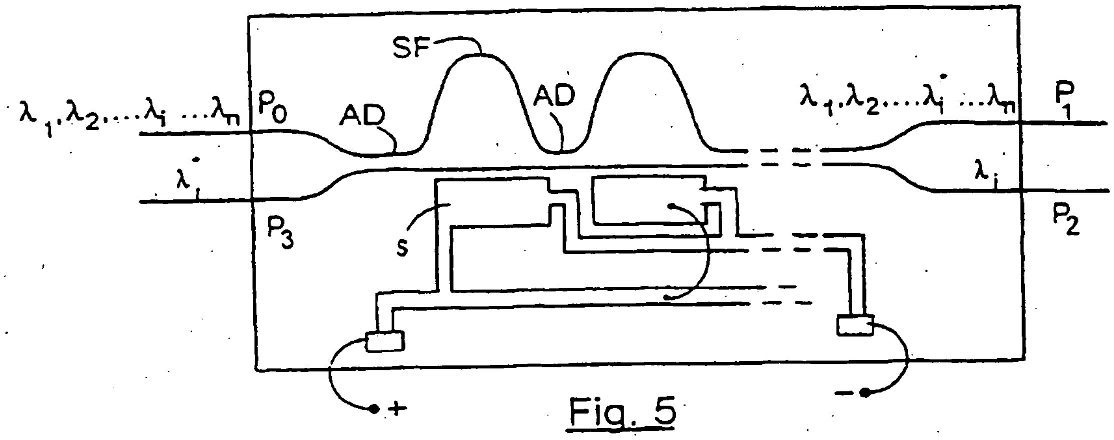


Fig. 5

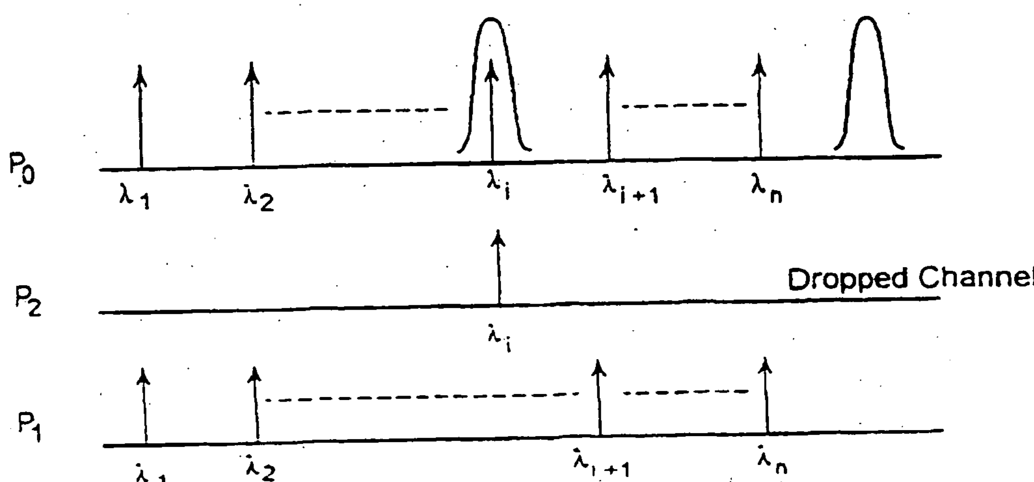


Fig. 6

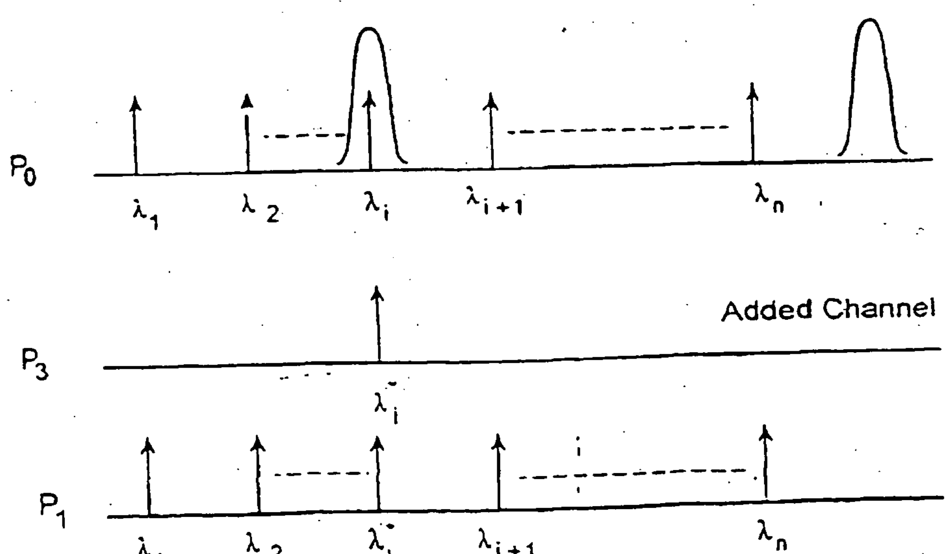


Fig. 7

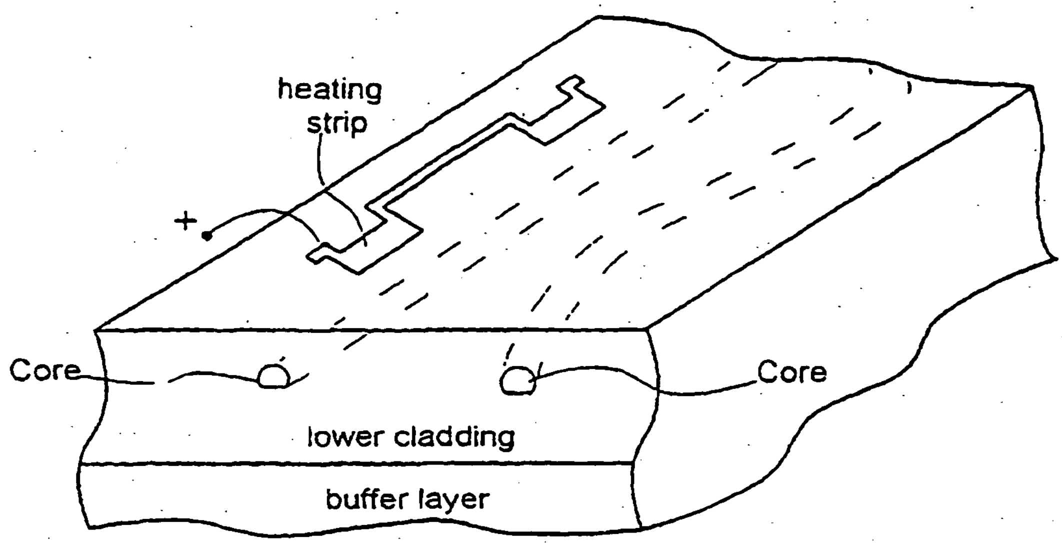

heating strip
+
Core
Core
lower cladding
buffer layer

Fig. 8

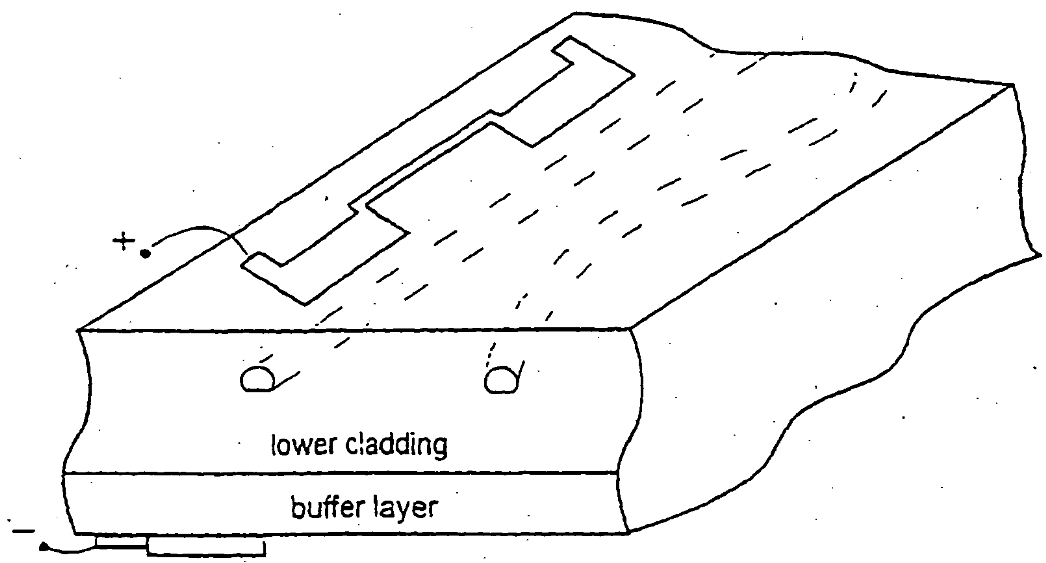

+
lower cladding
buffer layer
–

Fig. 9

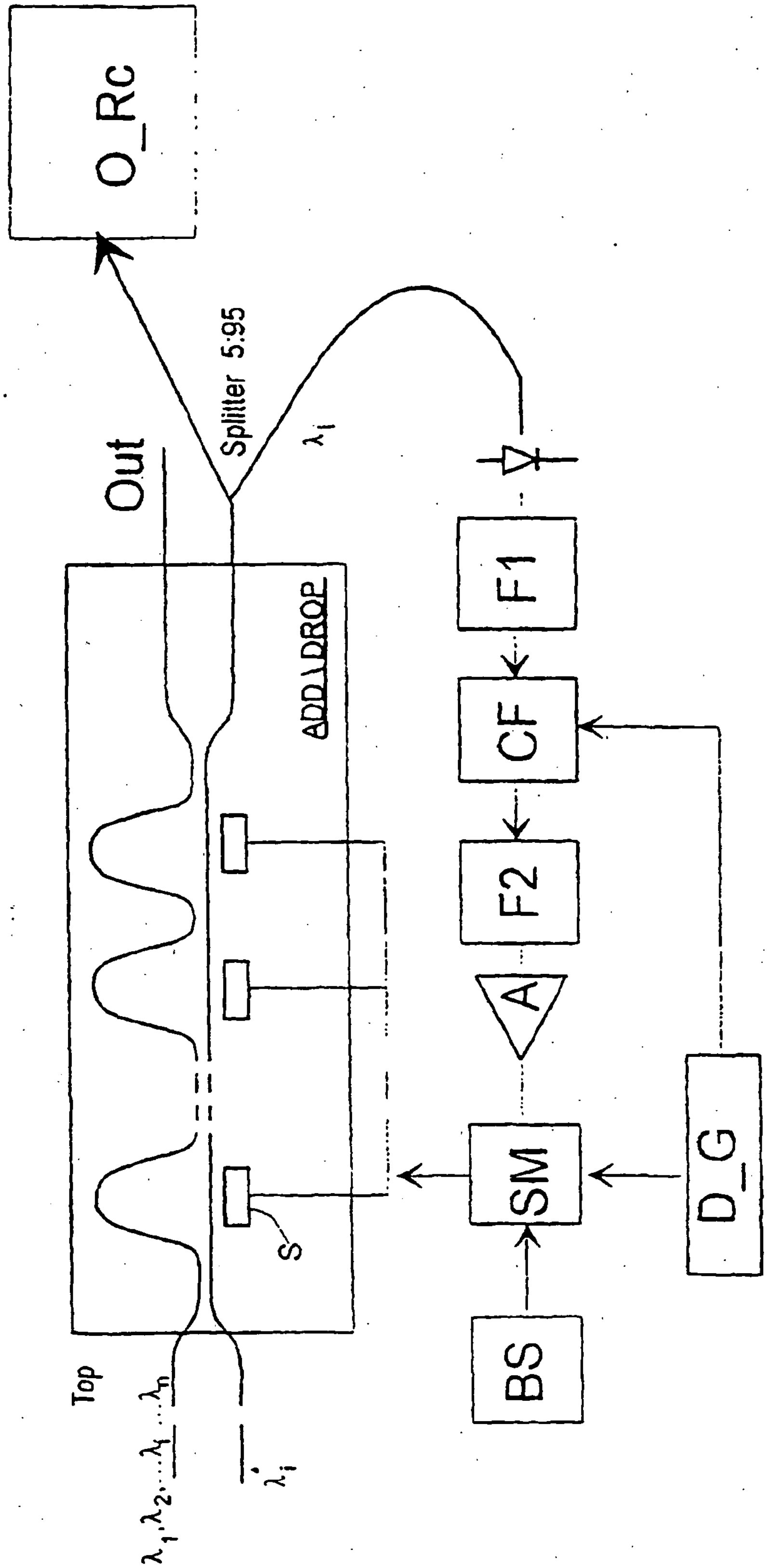

O_Rc
Out
Splitter 5:95
λ_i
ADD\DROP
F1
CF
F2
A
SM
D_G
BS
S
Top
$\lambda_1, \lambda_2, \ldots \lambda_i \ldots \lambda_n$
λ'_i

Fig. 10

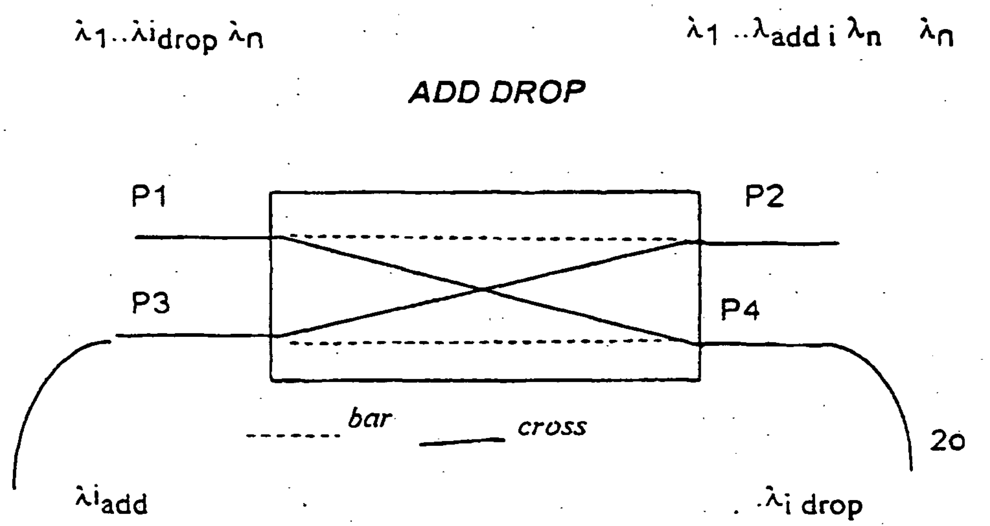

λ1..λidrop λn
λ1 ..λadd i λn λn
ADD DROP
P1
P2
P3
P4
bar
cross
20
λiadd
λi drop

Fig. 11

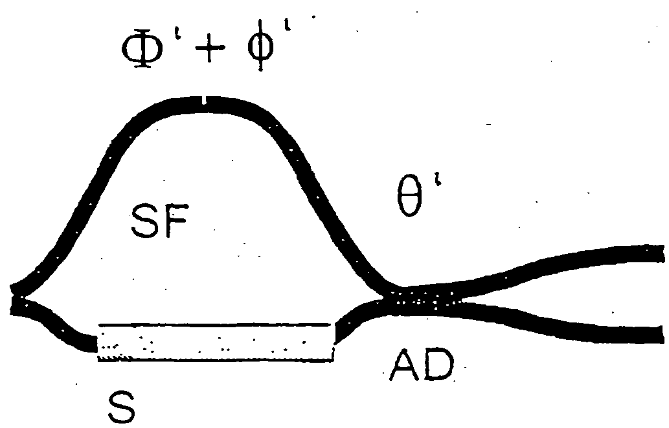

Φ' + φ'
SF
θ'
AD
S

Fig. 12

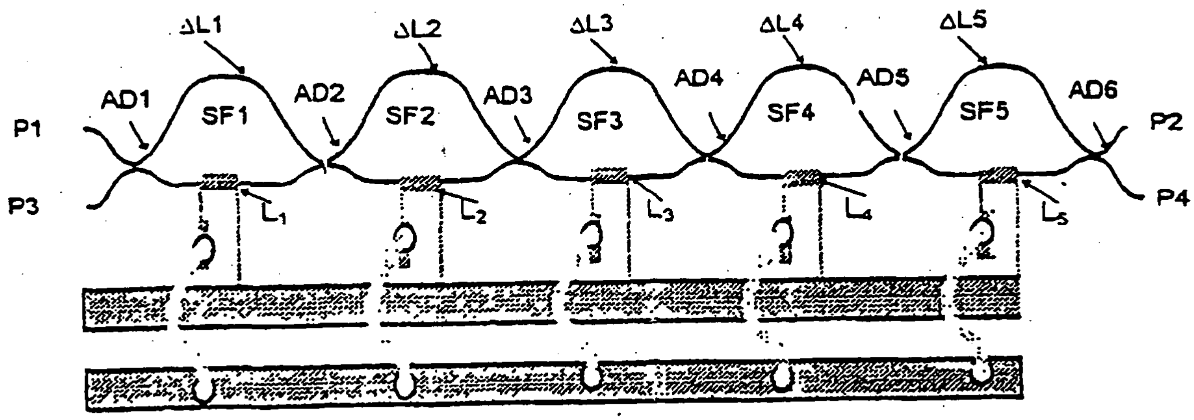

ΔL1
ΔL2
ΔL3
ΔL4
ΔL5
AD1
AD2
AD3
AD4
AD5
AD6
SF1
SF2
SF3
SF4
SF5
P1
P2
P3
P4
L1
L2
L3
L4
L5

Fig. 13

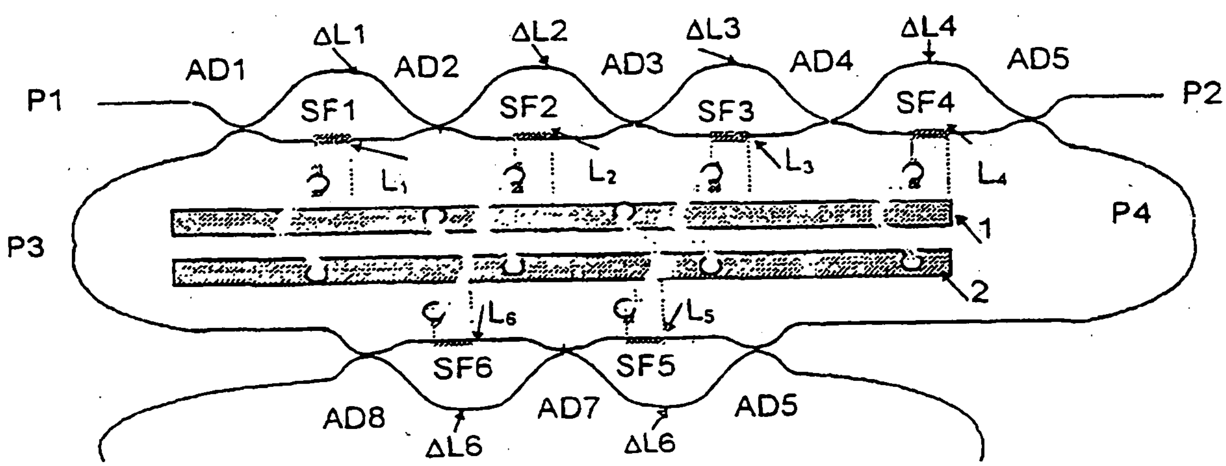

ΔL1
ΔL2
ΔL3
ΔL4
AD1
AD2
AD3
AD4
AD5
P1
P2
SF1
SF2
SF3
SF4
L1
L2
L3
L4
P3
P4
1
2
L6
L5
SF6
SF5
AD8
AD7
AD5
ΔL6
ΔL6

Fig. 19

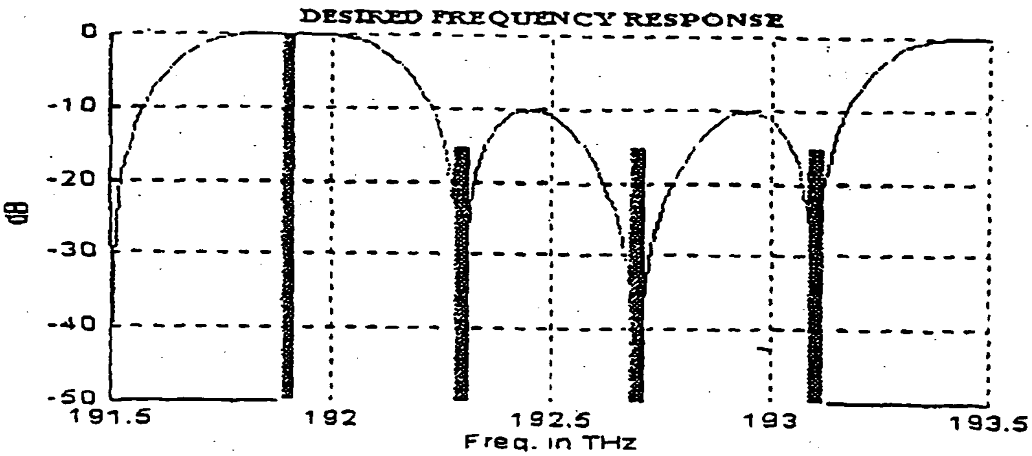

DESIRED FREQUENCY RESPONSE
0
-10
-20
-30
-40
-50
dB
191.5
192
192.5
193
193.5
Freq. in THz

Fig. 14

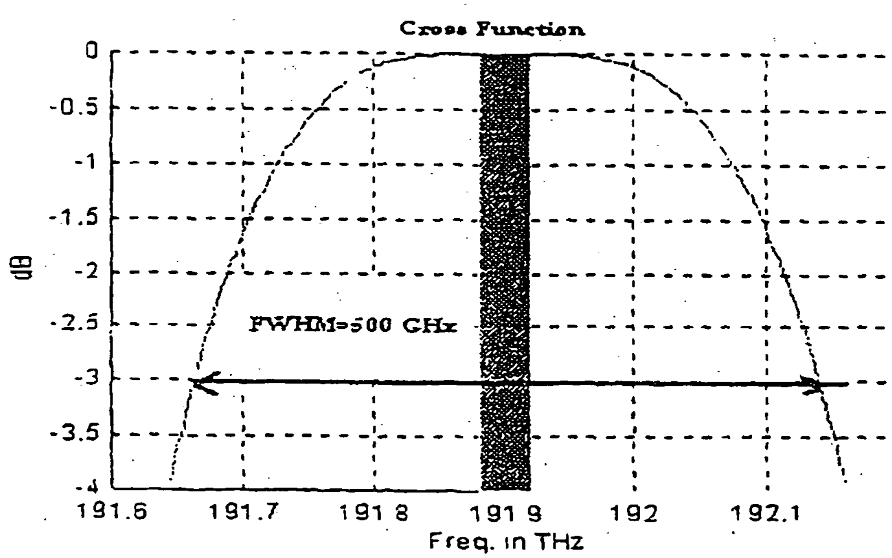
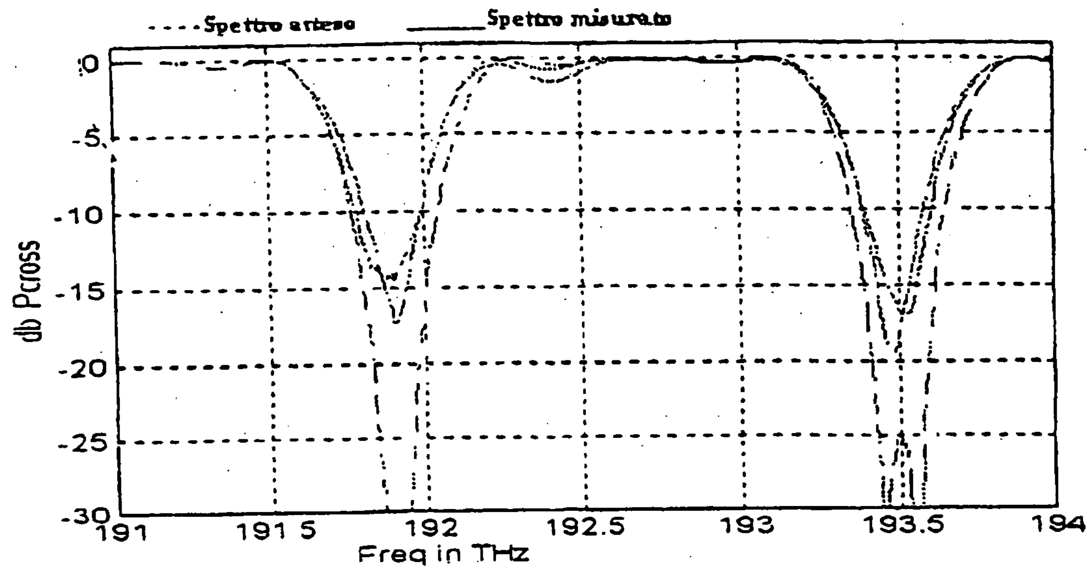
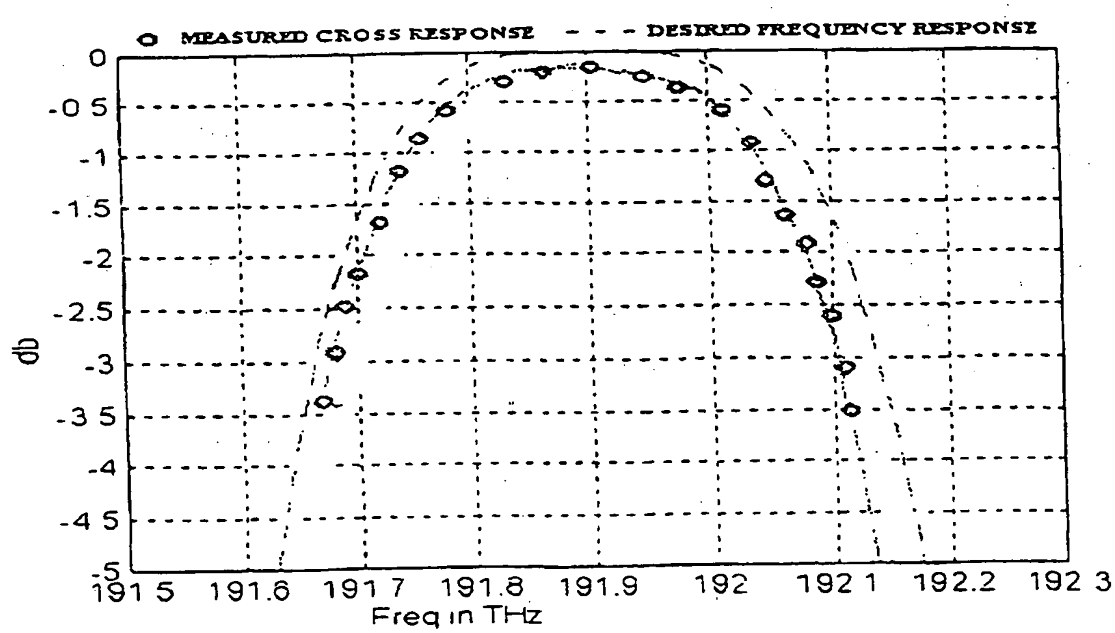

Cross Function
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
dB
FWHM=500 GHz
191.6
191.7
191.8
191.9
192
192.1
Freq. in THz

Fig. 15



----Spettro atteso
______Spettro misurato
0
-5
-10
-15
-20
-25
-30
db Pcross
191
191 5
192
192.5
193
193.5
194
Freq in THz

Fig. 16



o MEASURED CROSS RESPONSE
- - - DESIRED FREQUENCY RESPONSE
0
-0 5
-1
-1.5
-2
-2.5
-3
-3 5
-4
-4 5
-5
db
191 5
191.6
191 7
191.8
191.9
192
192 1
192.2
192 3
Freq in THz

Fig. 17

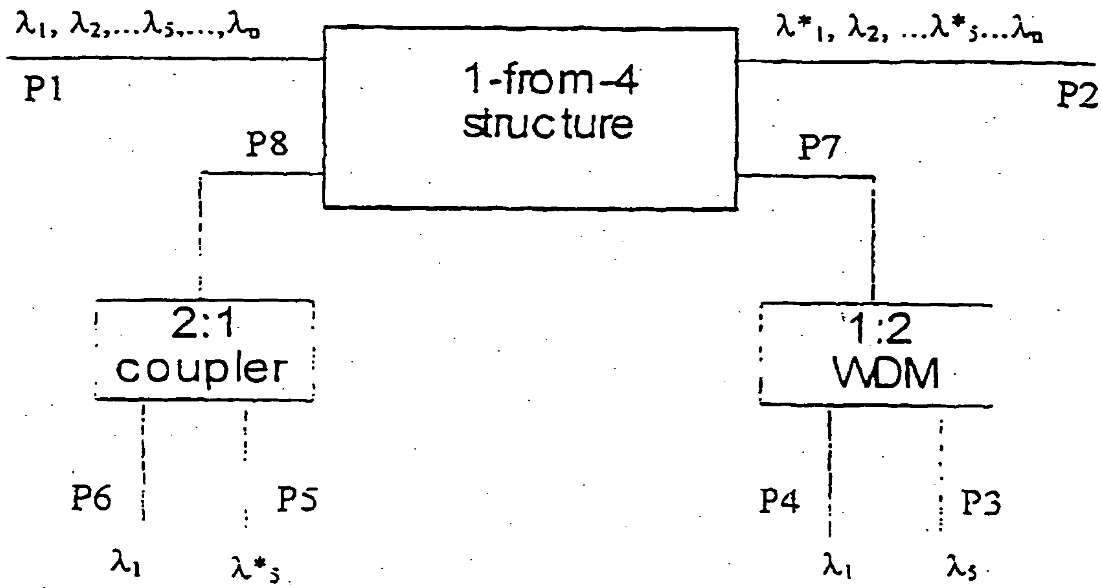

λ1, λ2,...λ5,...,λn
λ*1, λ2, ...λ*5...λn
P1
P2
1-from-4
structure
P8
P7
2:1
coupler
1:2
WDM
P6
P5
P4
P3
λ1
λ*5
λ1
λ5

Fig. 20

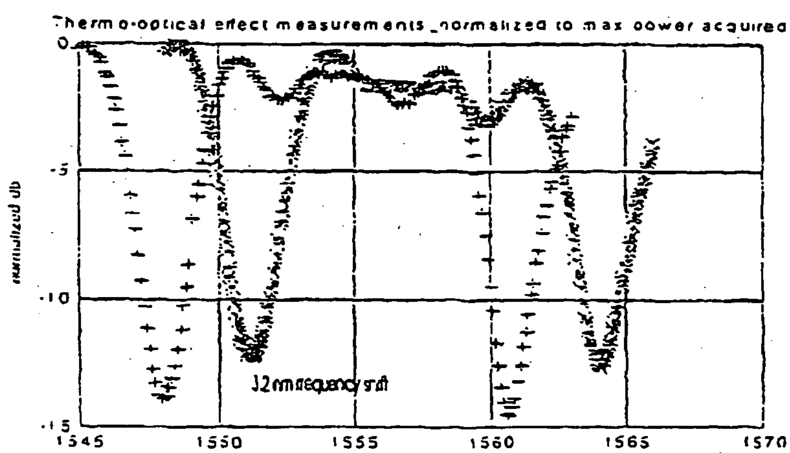

Thermo-optical effect measurements_normalized to max power acquired
normalized dB
12 nm frequency shift
0
-5
-10
-15
1545
1550
1555
1560
1565
1570

Fig. 18

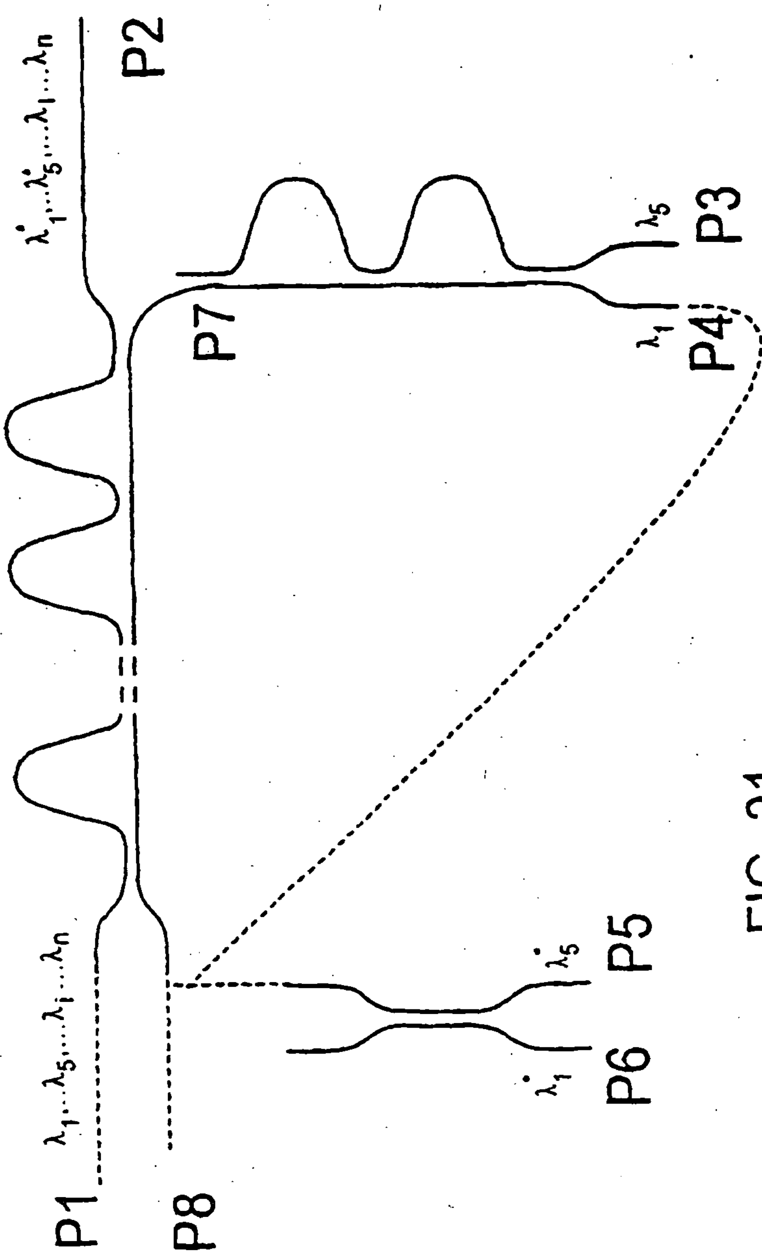

P1
P2
P3
P4
P5
P6
P7
P8
$\lambda_1 \ldots \lambda_5 \ldots \lambda_i \ldots \lambda_n$
$\dot{\lambda}_1 \ldots \dot{\lambda}_5 \ldots \lambda_i \ldots \lambda_n$
λ_5
λ_1
$\dot{\lambda}_5$
$\dot{\lambda}_1$

FIG. 21